MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Department of Aeronautics and Astronautics
16.010 / 16.020 Unified Engineering

Systems Problem #12

Issued: November 27, 2000 Due: Noon December 8, 2000

AIR DATA SYSTEM WIND TUNNEL LAB

On February 6, 1996, a Boeing B-757 crashed shortly after taking off from Puerto Plata, Dominican Republic. The preliminary report from the National Transportation Safety Board (NTSB) and an edited transcript of the cockpit voice recorder (CVR) are attached. From the CVR, it is clear that there was a problem with the aircraft's airspeed indications. This led to confusion in the cockpit as to whether the aircraft was flying too fast or too slow.

In this systems problem, you will perform some experimental tests of air data system components to investigate what may have led to the crash. The tests will be performed in small groups in the MIT Wright Brothers Wind Tunnel (WBWT). Unlike previous labs, we will not specify what data you should take. Instead, your lab group will determine what data are important to collect and how to best collect them. Thus, some pre-lab preparation is essential so that you arrive at the wind tunnel prepared to begin.

Objectives

At the end of this systems problem, you should be able to:

- Explain how air data systems compute airspeed
- Compute indicated airspeed when given static and stagnation pressure readings
- Operate the Wright Brothers Wind Tunnel safely
- Perform empirical pressure measurement collection using pitot tubes in a wind tunnel
- Apply empirical data to support or refute a hypothesis for the cause of an aviation accident

Air Data System Background

Air data systems rely on two primary sensor inputs to drive several cockpit instuments including the airspeed indicator, altimeter, and the vertical speed indicator.

The two sensor inputs are the static air pressure (p) and the stagnation pressure (p_0). The static pressure, p, is measured on an aircraft using a pressure transducer connected to a small hole in the side of the fuselage. Stagnation pressure, p_0, is measured using a pressure transducer connected to a pitot tube that has a hole that points forward into the airstream.

From Bernoulli's Equation,

$$p_0 = 1/2\ \rho\ v^2 + p \qquad (1)$$

stagnation pressure = dynamic pressure + static pressure

From this equation, true airspeed (v) is given by:

$$v = \sqrt{\frac{2(p_0 - p)}{\rho}} \qquad (2)$$

Airspeed indicators, however, do not have a direct measure of air density (ρ) and so do not actually display the *true airspeed* of the aircraft. Instead, they display the speed assuming that air density is at its standard sea level value (1.225 kg/m^3). Assuming there are no other errors, the computed value of v is then called the *indicated airspeed*. Seen another way, since the airspeed indicator uses ($p_0 - p$) it actually is a form of *dynamic pressure meter*. Since the aircraft's aerodynamic characteristics (such as Lift and Drag) are direct functions of dynamic pressure, the aircraft will generally behave similarly at the same indicated airspeed regardless of its altitude. At high Mach numbers, however, compressibility effects may change this behavior.

Static pressure information is also used to drive the altimeter and the vertical speed indicator. A small weather vane on the side of the aircraft measures the *angle of attack* : the angle between the air flow and a reference line running from the nose to the tail of the aircraft. If the angle of attack gets too large (the nose is pitched far up relative to the air flow), the wing cannot produce the necessary lift force, and the aircraft will stall.

Jet transports like the B-757 have 3 independent air data systems as shown in the figure on the attached page. Each air data system has a separate stagnation pitot probe and separate static pressure sensors.

The Wright Brothers Wind Tunnel

The Wright Brothers Wind Tunnel has a 7 ft x 10 ft test section, allowing you to walk around inside (at least when it is not running or when it is running at slow speeds). The tunnel can be run at speeds up to 100 mph. In the wind tunnel, you will have access to several different pressure measuring devices:

Pitot Tube A is a simple stagnation pressure probe.

Pitot Tube B is a combined pitot-static tube. It has one opening on the side for measuring static pressure, and one opening at the tip of the tube for measuring stagnation pressure.

Pitot Tube X is located at the mouth of the wind tunnel to measure stagnation pressure.

Static Pressure Port Y is on the side of the test section and provides a static pressure reading.

A number of other static pressure ports are also available along the side of the test section.

Since they have been carefully calibrated, we will consider Pitot Tube X and Pressure Port Y to provide "truth" data. Based on X and Y, the wind tunnel's airspeed can be computed and used as a reference.

In essence, you have two air data systems to examine in the lab relative to the truth data from X and Y. Tube B provides a set of static and stagnation pressures that can be used to compute airspeed. Also, Tube A in conjunction with the static pressure ports on the walls of the test section can be used to compute airspeed.

1. Sign Up for Lab Slot and Form Groups

Your lab group will work as a team on most of this systems problem. In particular, your group will design its own test plan for the wind tunnel. This plan must be completed before arriving at the WBWT. So, it is important that you get a team formed up quickly so that you have time to prepare for the lab.

Sign-up sheets for lab sessions are posted outside the TA office. Each group is limited to no more than 7 students.

You must be signed up for a lab slot by 5pm Tuesday November 28 so that you know who your group is in time to develop a test plan. Failure to sign up in time will result in a 5 point penalty in your systems problem grade.

2. Pre-Lab Test Plan Development

The group of students you are signed up with for the wind tunnel test session will be working together on the data collection portion of this systems problem. You must meet as a group to develop a test plan and then execute your plan in the wind tunnel. *This test plan must be completed before arrival at the wind tunnel for the data-collection session. Your plan will be inspected before you are allowed to collect data.*

Your test plan should include:

(a) A specific test plan for Pitot Tube B so that you can plot its airspeed readings vs. the truth readings from X and Y.

(b) A specific test plan for Tube A + static ports so that you can plot the airspeed they measure vs. the truth readings from X and Y.

(c) A short written statement of your group's hypothesis for the accident.

(d) A specific list of test conditions that will allow your group to support or refute your hypothesis.

Each test plan may simply be a table or matrix showing what conditions you will run the tunnel at, and what measurements will be taken in each condition. Be sure to also think through how long it may take to run the tunnel and record data — try to plan for no more than 1 hr of data collection time.

3. Collect Data

Once your test plan is ready, go to the wind tunnel (building 17) and collect your data. You may modify the test plan as you go, but you must report any changes in the final write-up.

4. Lab Write-Up

On Friday, December 8, you should turn in the following:

(a) A list of the students in your lab group.

(b) Your group's test plan and collected data. It is acceptable to turn in a xerox copy of the group's test matrix and data values, or this can be done individually. Clearly indicate what each data value represents in your table.

(c) A short discussion of changes to the test plan, if any, that were made while in the wind tunnel and why the changes were made (individual write-up).

(d) Two plots showing the relationships between (1) airspeed from tube B vs. airspeed from X&Y, and (2) airspeed from tube A and static ports vs. X&Y. You should draw up these plots on your own.

(e) Your hypothesis for the cause of the accident. This may be xeroxed between team members.

(f) Any relevant data plots to support or refute your accident hypothesis. You should draw up these plots individually.

(g) A short discussion of the data relating to the accident hypothesis. Did the data you collected support the hypothesis? How confident are you that you have determined the cause of the accident? What other information might you want to help solve the case?

NTSB Identification: DCA96RA030
Nonscheduled 14 CFR 129 operation of BIRGENAIR
Accident occurred FEB-06-96 at PUERTO PLATA
Aircraft: BOEING 757-200, registration: TCGEN
Injuries: 189 Fatal.

On February 6, 1996, about 2348 Atlantic standard time, a Boeing 757-200, TC-GEN registered to Birgenair, crashed near Cabarate Beach near Puerto Plata, Dominican Republic, while on a passenger charter flight to Frankfurt, Germany. Visual meteorological conditions prevailed in the area at the time of the accident. The airplane was destroyed by impact forces with the water, and 176 passengers and 13 crew members were fatally injured. The flight departed General Gregorio Luperon International Airport in Puerto Plata, Dominican Republic at 2343 Atlantic standard time. The airplane was climbing through 7000 feet when it was observed on radar to start a right descending turn disappearing from radar descending through 5000 feet radio contact was lost about the same time. The flight was a charter flight for Alas Nacionales destined to Frankfurt, Germany with intermediate stops in Gander, Newfoundland and Berlin, Germany. Birgenair is based in Istanbul, Turkey and leases to Alas Nacionales a Dominican Republic company. The investigation is under the jurisdiction of the Dominican Republic Aviation Authorities. This report is filed for information purposes only and contains only that information released by the Dominican Republic Aviation Authorities. For additional information contact Director General de Aeronautica Civil Edificio de Oficinas Gubernamentales II Blogue "A" 2da Planta 9 NO Piso AV 27 de Febrero Santo Domingo, Dominican Republic Telephone (809) 221-7902 A video tape of the DFDR and CVR recovery activities is available.

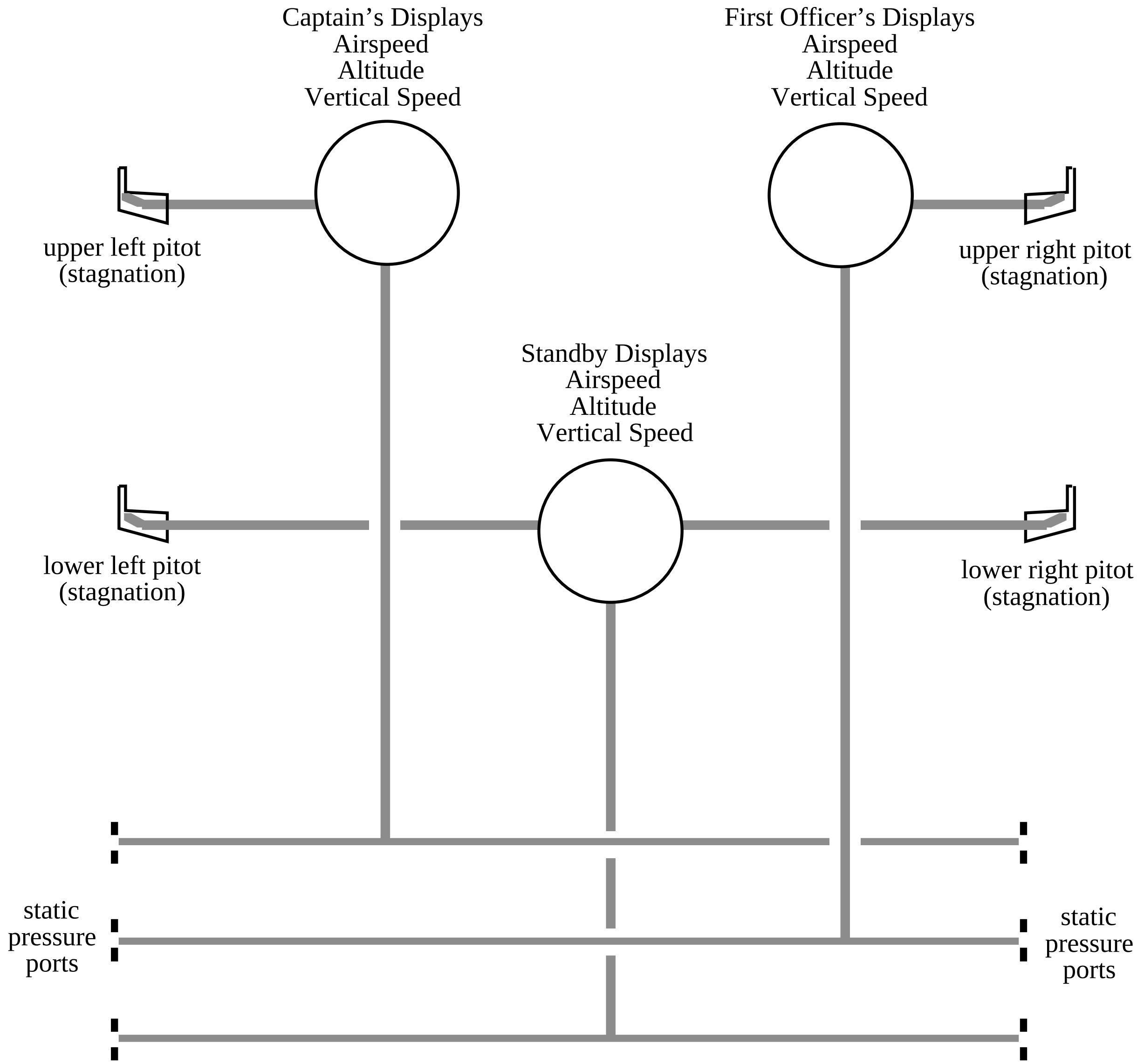
Edited Cockpit Voice Recorder Transcript

(showing only the most relevent communications)

Adapted from complete transcript collected by Prof. Peter Ladkin, Bielefeld University

The Captain was flying (looking out the window), with the first officer (F/O) watching instruments and reading airspeeds as the aircraft took off. Background sounds in *italics*. Explanatory comments in [[double brackets]].

Time	Source	Content
42:30	—	*sound of increasing engine noise as the aircraft rolls down the runway*
42:38	F/O	power's set [[the throttles have been advanced to takeoff thrust]]
42:45	F/O	eighty knots [[F/O is reading 80 kt on his airspeed indicator]]
42:48	CAPT	my airspeed indicator's not working [[Captain’s airspeed isn’t changing]]
42:51	F/O	yours is not working
42:52	F/O	one twenty [[F/O is reading 120 kt on his airspeed indicator]]
42:54	CAPT	is yours working?
42:54	F/O	yes sir
42:55	CAPT	you tell me [[Capt is asking F/O to read off airspeeds for him]]
42:58	F/O	rotate [[F/O notes they have reached the speed at which time the aircraft’s nose is pitched upward]]
43:22	F/O	It began to operate [[referring to the Captain’s airspeed indicator, which is now starting to increase]]
44:50	CAPT	there is something wrong there are some problems
45:06	CAPT	okay there is something crazy do you see it
45:08	F/O	there is something crazy there at this moment two hundred only is mine and decreasing sir [[F/O referring to his airspeed indicator reading 200 kt and decreasing]]
45:14	CAPT	both of them [[airspeeds]] are wrong. what can we do?
45:50	—	*sound of aircraft overspeed warning* [[this is computed from the Captain’s airspeed indicator]]
46:01	CAPT	pull the airspeed [[slow down]] we will see
46:01	—	*overspeed warning stops*
46:02	F/O	now it is three hundred and fifty yes [[reading the Captain’s airspeed, which is very high]]
46:14	—	*sound of stick shaker* [[impending stall, going too slow]] *starts and continues to end of recording*. [[This is computed from the angle of attack vane]]
46:29	F/O	nose down [[this will speed up the aircraft]]
46:45	F/O	[[increase]] thrust [[to speed up the aircraft]]
47:01	CAPT	not climb? what am I to do?
47:05	F/O	you may level off, altitude okay, I am selecting the altitude hold sir
47:14	CAPT	[[advance the]] thrust levers, thrust thrust thrust thrust
47:16	F/O	retard [[pull the throttles back]]
47:16	CAPT	thrust, don't pull back, don't pull back, don't pull back, don't pull back
47:18	F/O	okay open open [[throttles forward]]
47:19	CAPT	don't pull back, please don't pull back
47:21	F/O	open sir, open
47:24	F/O	sir pull up
47:25	CAPT	what's happening
47:27	F/O	oh what's happening
47:31	—	*sink rate whoop whoop pull up warning starts and continues until the end*
47:39		*end of recording*



Boeing 757 Air Data System Schematic

(Simplified from the Boeing pilot's operating manual)